

Weather Note

RECURVATURE OF HURRICANE CLEO, 1964, AND ASSOCIATED 500-MB. STREAMLINE ANALYSIS

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1. MOVEMENT OF CLEO

Tropical Storm Cleo developed over the South Atlantic near 13°N., 47°W., on August 20, 1964. It reached hurricane intensity the following day. Cleo moved west-northwestward for the first three days, on a track essentially parallel to the deep easterly flow in which the storm was embedded. This typical course brought Cleo into the eastern Caribbean on August 22, and into the north-central portion of the Caribbean by August 24 (fig. 1).

Forecasting the movement of hurricanes is habitually fraught with conflicting indications. This was particularly true with Cleo on August 24. Persistence, and a typical path around the western side of the dominant and stationary Bermuda High (fig. 1), indicated westward movement into the Gulf of Mexico. From climatology [1], tropical storms moving westward south of the Dominican Republic and eastern Cuba, at this time of year, would be expected to continue moving westward. Instead, Cleo took a less likely path northward, unusual in that it was directly toward a strong ridge at the surface and aloft. Admittedly, a few developments were noted that might have been construed to foretell the subsequent atypical recurvature. This note describes a feature of upper-level streamline analysis that may serve as an additional parameter useful for anticipating recurvature.

2. THE HYPERBOLIC AXIS

The line extending from the storm center through the hyperbolic point of the streamline analysis will be called the hyperbolic axis, labeled H_1H_2 in figure 1. This line is an analytical feature of the streamline analysis that appears to have a unique location and orientation with respect to the prevailing circulation surrounding a tropical storm. The position of the axis is sensitive to the general structure of the anticyclonic flow immediately in advance and to the rear of the storm, features that are the basis of a useful empirical rule for forecasting hurricane movement, as explained later in this section.

The hyperbolic point, per se, is often difficult, if not impossible, to locate precisely because data are either sparse or are inappropriately distributed. The hyperbolic axis, however, can be located with reasonable accuracy

when it is extended through the general area of the hyperbolic point into the remnant wave, usually found farther equatorward from the tropical storm, in the easterlies. Greater dependability appears to be attained in the orientation of the hyperbolic axis than in the placement of the hyperbolic point. The hyperbolic axis, a compromise feature between two elements of the circulation, viz., the hyperbolic point and the adjacent inverted trough, appears to maintain better continuity, perhaps because it is an extensive configuration for which more data are available than for the hyperbolic point alone. Future studies may reveal a significance to the varying distance between the storm center and the hyperbolic point. However, the case made here is for attention to the orientation of the hyperbolic axis in forecasting tropical storm paths. If the net effect of the circulation, in depth, surrounding a tropical storm is a major factor in the storm's movement, then the hyperbolic axis at an intermediate upper level, as a representative feature of the peripheral circulation, is likewise a factor.

The hyperbolic axis, particularly the portion outside the hyperbolic point, is sandwiched between anticyclonic flow (see especially fig. 2), representing a large part of the steering circulation. Steering is considered the physical basis accounting for the success of the forecasting rule by Kraft and Conner [2] that a tropical storm moves along a path approximately parallel to the line connecting the peak of the ridge behind the storm to the peak of the ridge ahead of the storm. This rule, in application, requires homogeneity (essentially zero baroclinicity) of the air mass surrounding the storm—otherwise a correction must be applied. The same restriction applies when steering storms by the orientation of the hyperbolic axis. Unfortunately, experience has shown that after recurvature, or beginning with the late stages of recurvature, the hyperbolic axis generally becomes a less reliable feature of the analysis. While this has been attributed, in part, to the onset of baroclinicity, an attempt to account more fully for this behavior may be worthy of future study.

The innovation we are suggesting is an extension of earlier recommendations by Sherman and LaSeur [7] for reconnaissance of the "complete hurricane" and use of

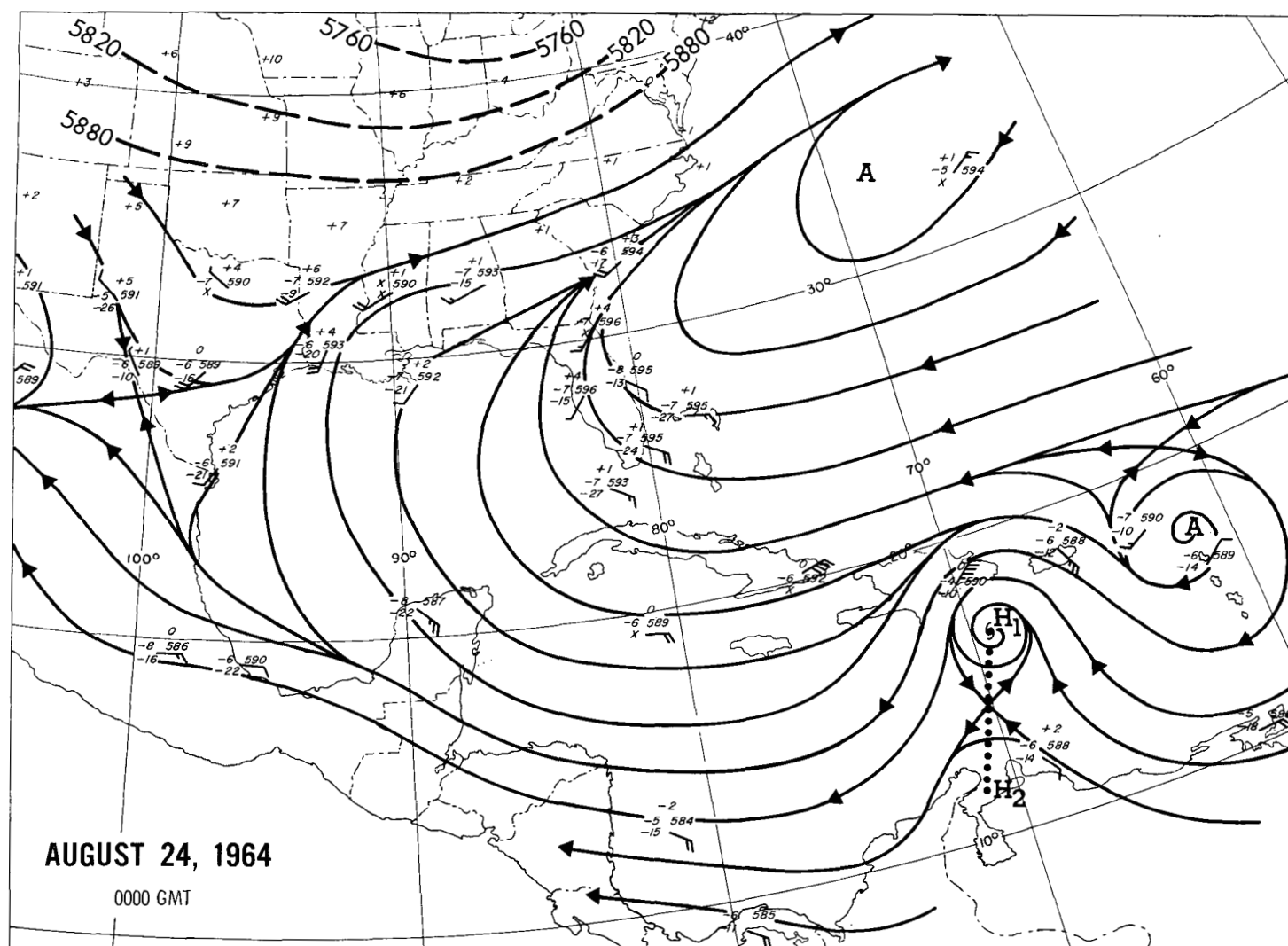


FIGURE 1.—Hurricane Cleo, 500-mb. streamline analysis, 0000 GMT August 24, 1964. Solid lines are streamlines, heavy dotted line the hyperbolic axis (see text). "A" designates anticyclonic center, "C", cyclonic center.

the hyperbolic point. Assuming the axis to be sensitive to the steering flow, we find it oriented 90 deg. to the left of the storm path (figs. 1 through 7), prior to the onset of baroclinicity.

3. SYNOPTIC COMMENTARY

The 500-mb. streamline analysis for August 24, 0000 GMT (fig. 1) was the first to show a break in the deep easterly flow in which Cleo was embedded. An anticyclonic flow pattern appeared over the Leeward Islands, as indicated by the reported winds. Whether this feature resulted from anticyclogenesis or from translation, could not be resolved by forecast deadline time, because of insufficient data upstream. The forecast consensus at this time, based on (1) the dominant ridge to the north, (2) climatology, (3) persistence, and (4) objective techniques, indicated no major change in course or speed for

the next 24 to 48 hr. The forecast called for a track passing near or just south of Jamaica.

By August 25, 0000 GMT (fig. 2), the developing ridge over the eastern Caribbean had become a dominant feature of the analysis. The hyperbolic axis was parallel to this ridge line—oriented somewhat more northeast-southwest than previously. Greater cognizance of these features and placing more weight on their forecast implications could have led to predicting a somewhat more northerly track than did the coordinated operational forecast for the next 24 to 36 hr., which called for continued movement west-northwestward, parallel to the southern coast of Cuba. Beyond this period, based on mid-latitude developments, mild indications for weakening of the ridge over southeastern United States were noted. Some future recurvature was therefore indicated, but hardly sufficient to bring Cleo into Florida.

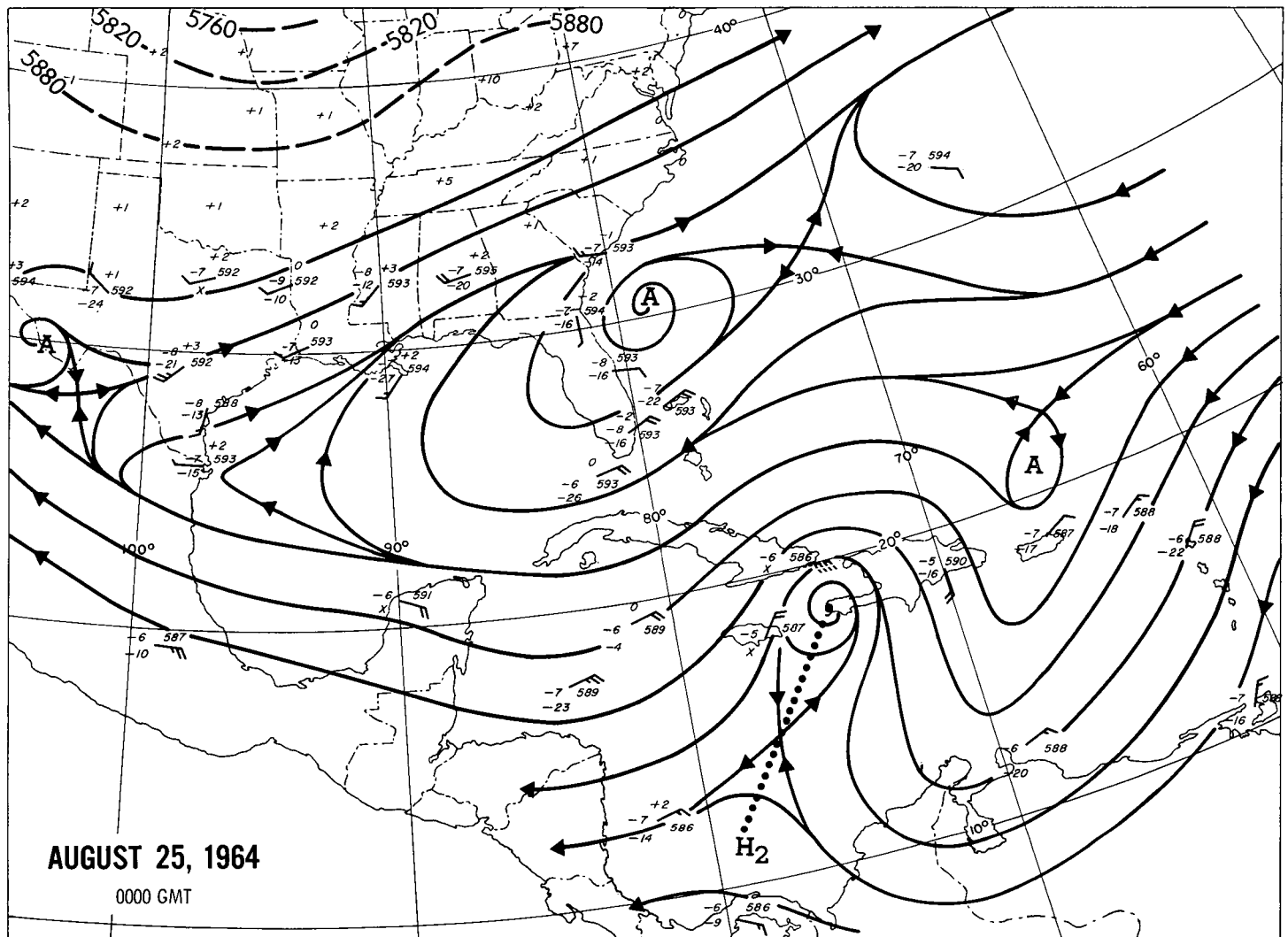


FIGURE 2.—Streamlines, hurricane Cleo, 0000 GMT August 25, 1964.

On August 26, 0000 GMT (fig. 3) the placement of the hyperbolic axis near Swan Island and Grand Cayman appeared to achieve optimum compatibility with the neighboring wind field. Good continuity prevailed between the current location and the position 12 hr. earlier (not illustrated) just beyond San Andres, which had experienced a northeast to southeast windshift, and also a position 6 hr. later just beyond Swan Island, where the wind had changed to south-southwest.

The ridge following Cleo had built westward into the western Caribbean. The same mid-latitude trends observed 24 hr. earlier remained in effect.

About 8 hr. later, Cleo had decelerated to 5 kt. or less, and was moving northwestward. The center was near the south-central coast of Cuba.

In the light of overall conditions as outlined, it may be of interest to mention that in the forecast coordination

(at about 0800 GMT of the 26th) under operational conditions, the possibilities of a straight northward movement were discussed, and one suggested track was for Cleo to pass near or slightly east of Miami. Six hours later the coordinated forecast did indicate an almost northward track.

On the intermediate chart for August 26, 1200 GMT (not illustrated), the eye of the storm, having crossed the island, was near the north-central Cuban coast. The anticyclone to the rear of the storm had moved over the western Caribbean and had the appearance of a closed circulation to the south of Cleo. The hyperbolic axis had approached the Yucatan Peninsula.

On the chart for August 27, 0000 GMT (fig. 4), Cleo is shown approaching Miami. The position of the hyperbolic axis was determined by emphasis on continuity because of lack of data in the Gulf of Mexico.

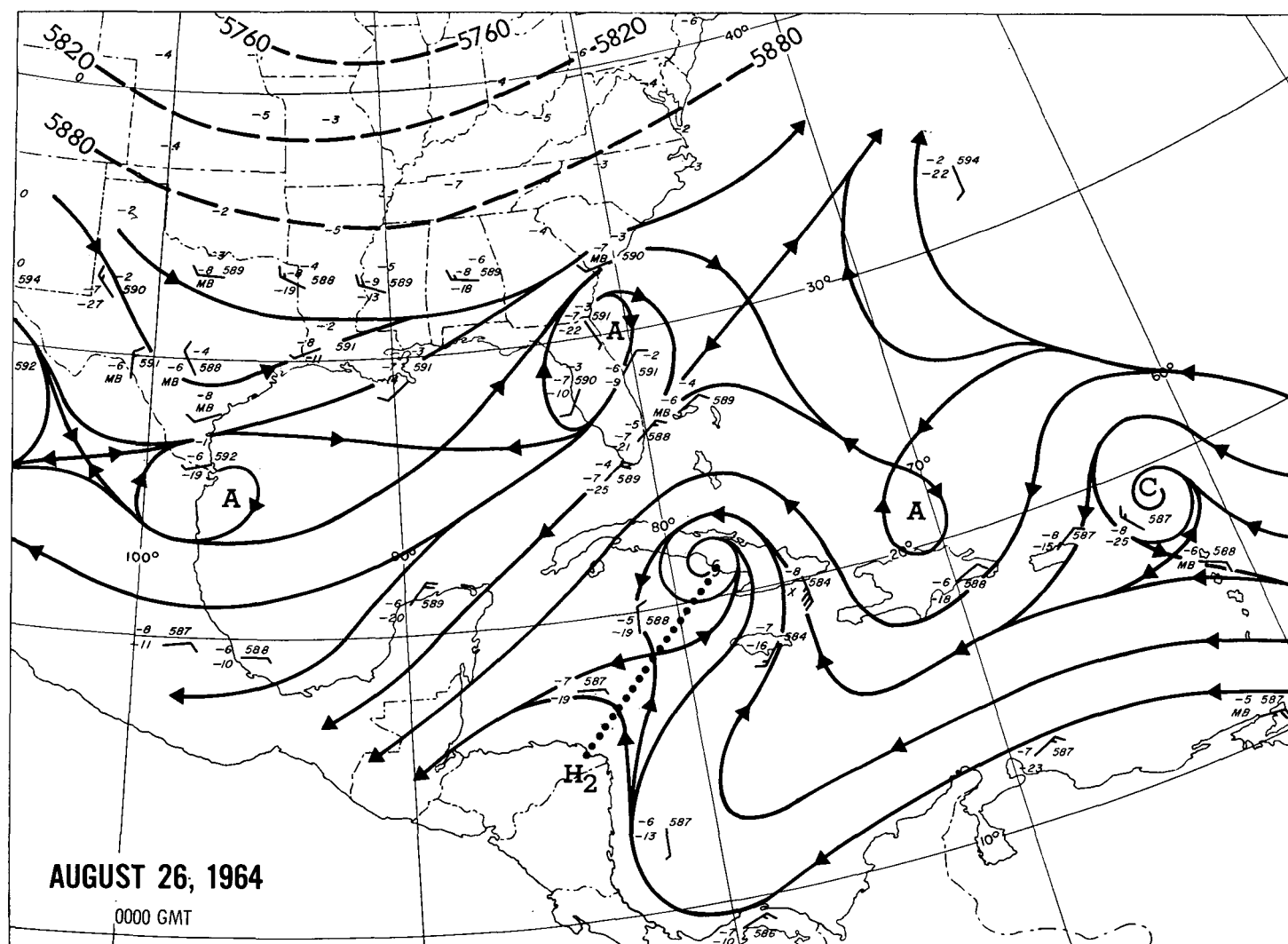


FIGURE 3.—Streamlines, hurricane Cleo, 0000 GMT August 26, 1964.

4. REORIENTATION OF THE HYPERBOLIC AXIS WITH CHANGES IN STEERING FLOW

Figure 5 shows the track of Cleo and the position of the hyperbolic axis at several selected map times. The reorientation of the axis in conformity with the recurvature of Cleo is apparent.

The following calculation is interesting, and possibly significant. If the point, H_2 , (fig. 5) is arbitrarily chosen 6° equatorward from the center of Cleo along the hyperbolic axis, a distance sufficient to put the point outside the hurricane circulation, and the speed of the point, H_2 , is computed, we find that it moved concentrically parallel to the path of Cleo at roughly 7° of latitude per 24 hr., or 20 m.p.h. This is the approximate speed at which Cleo was moving when it entered the Caribbean and started decelerating as recurvature occurred. Therefore, this peripheral portion of the hyperbolic axis did not slow its forward speed, as did the storm center. The result was a reorientation of the axis as recurvature took place.

5. A CASE OF NON-RECURVATURE

Hurricane Dora, 1964, was selected to illustrate the steadfast orientation of the hyperbolic axis that is indicative of no recurvature. Figures 6 and 7 show 500-mb. streamline analysis while Dora was approximately 36 and 12 hr., respectively, from the Florida coast. The hyperbolic axis maintained an approximate north-south orientation. A notable difference in the wind flow pattern around Dora, as compared to Cleo, was the absence of a developing strong ridge to the east or southeast, and little tendency for weakening of the ridge ahead of Dora. The consequential steering effects on Dora resulting from hurricane Ethel, located 15° to 20° of longitude upstream, a distance indicated by Riehl [4] to be an average wavelength in the easterlies, have been disregarded for this study.

6. STREAMLINE ANALYSIS AT 500 MB.

The general inadequacy of height or pressure analysis at tropical latitudes has been well documented. While

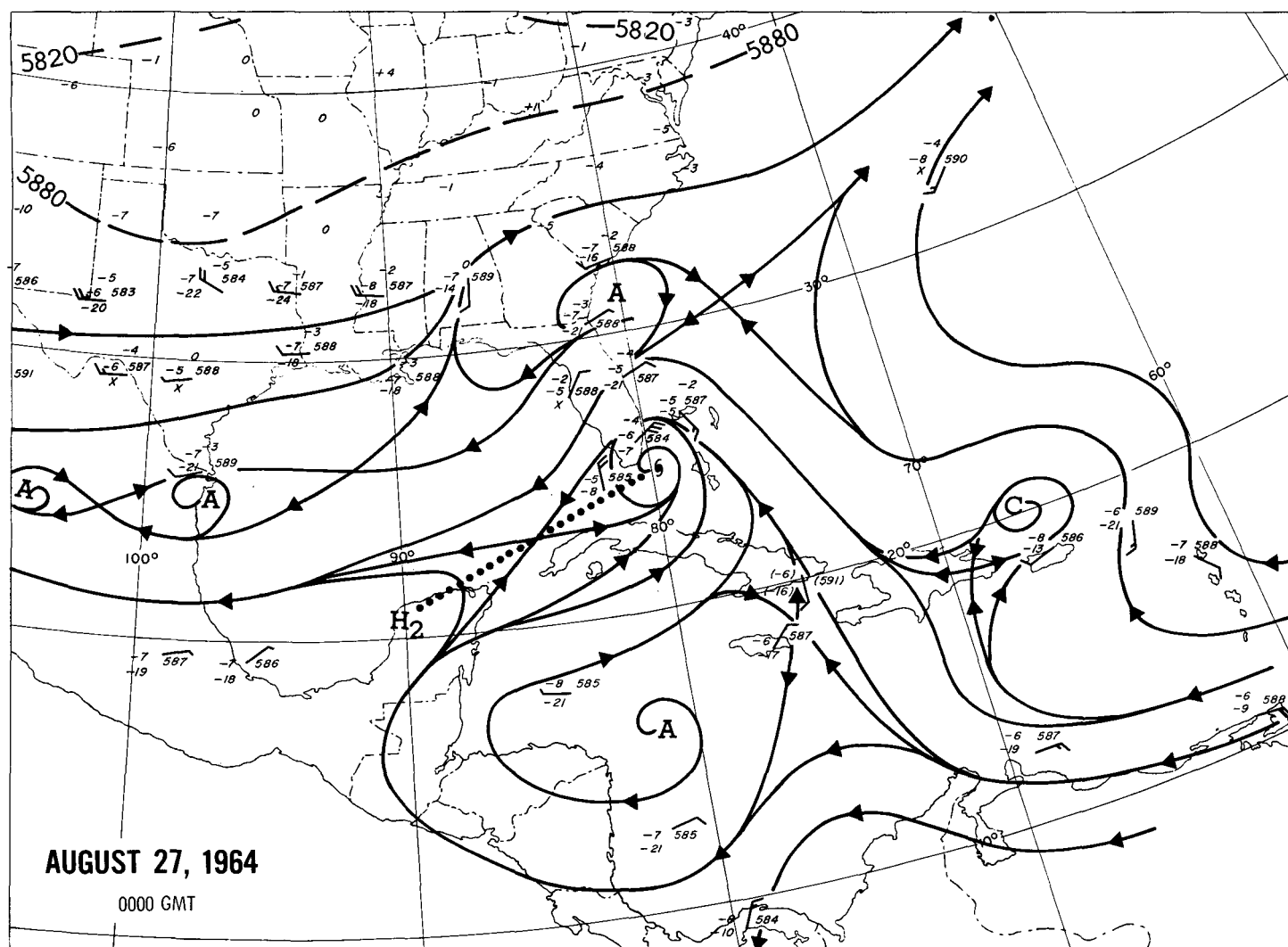


FIGURE 4.—Streamlines, hurricane Cleo, 0000 GMT August 27, 1964.

we have resorted to streamlines the subjectivity inherent in such analyses is recognized. The characteristic sparsity of data over the Tropics is even more acute when an analysis is attempted at upper levels. Most hurricanes approach the United States coast through areas where the paucity of data is more apparent than was the case with Cleo.

The streamline analysis, during Cleo's passage through the Caribbean into the period of recurvature, has the appearance of being both logical and consistent. Within acceptable limits, successive maps showed good continuity in several of the characteristic configurations of streamline analysis—singular points, asymptotes, troughs, and particularly the hyperbolic axis and the associated ridges preceding and following the axis.

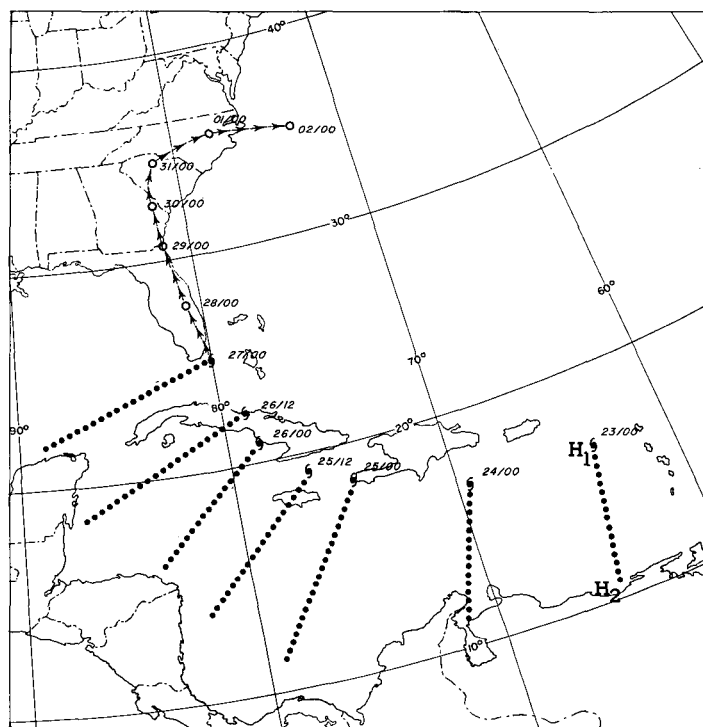


FIGURE 5.—Track of Cleo with hyperbolic axis at selected times prior to and at recurvature.

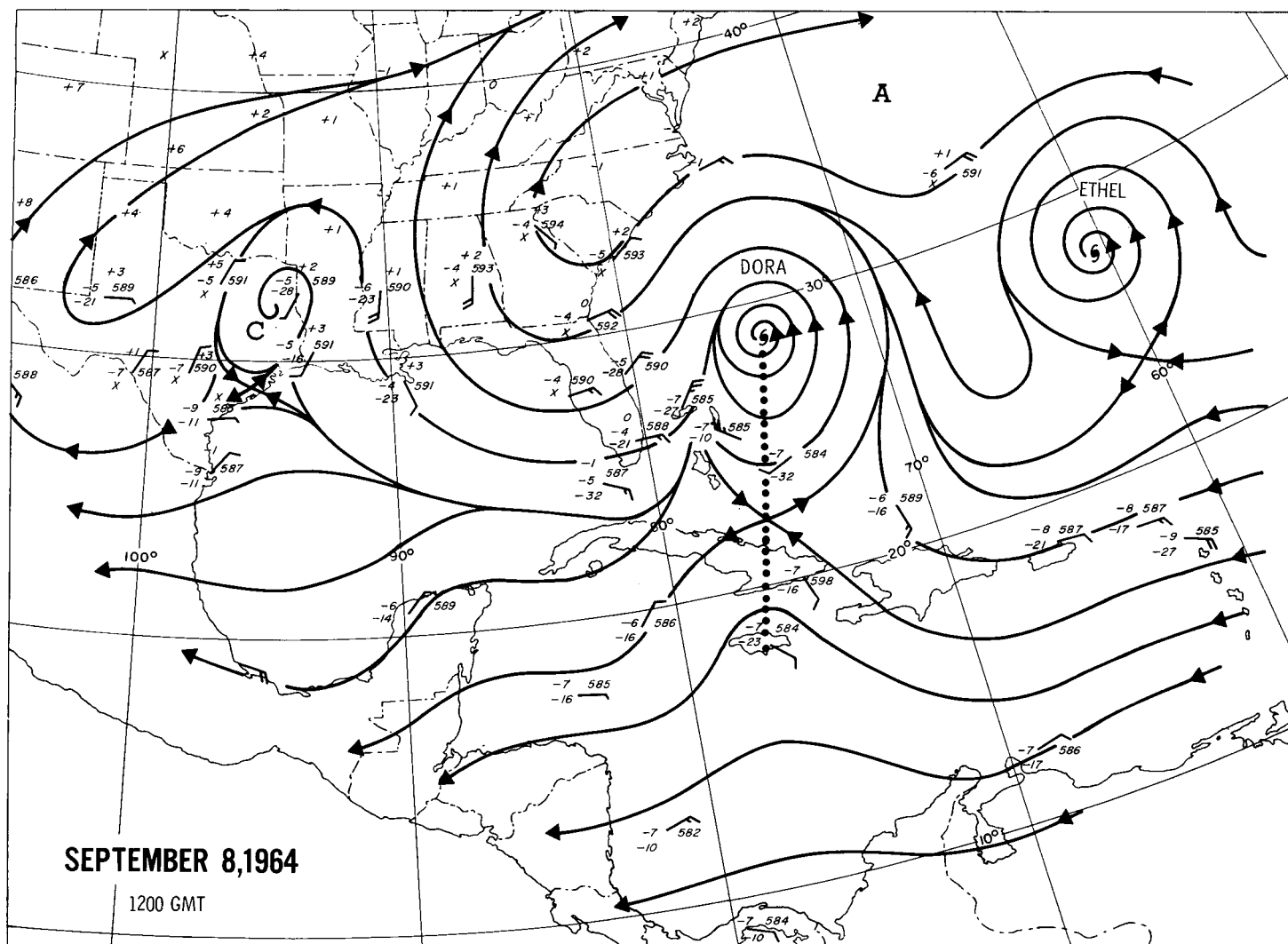


FIGURE 6.—Hurricane Dora, 500-mb. streamline analysis, 1200 GMT September 8, 1964. Solid lines are streamlines, heavy dotted line the hyperbolic axis. "A" designates anticyclonic center, "C", cyclonic center.

In the contrasting case for no recurvature, the streamline analysis for Dora showed steadfast orientation of the hyperbolic axis and the associated ridges.

Studies by Sherman [5], Sherman and Carino [6], and Sherman and LaSeur [7] have described the advantages that could accrue from considering the behavior of the hyperbolic point in tropical storm analysis and forecasting. Wobus [8] has presented interesting streamline models of hurricane low-level flow. His so-called "throat" trough coincides with our hyperbolic axis. However, the attention in these studies was, for the most part, upon surface or low-level analysis, as it was in the analysis of hurricane Edna, 1954, by Malkin and Holzworth [3]. Streamline analyses at several upper levels, as well as at the surface, may in the future, with machine methods, be incorporated into an integrated picture of tropical storm circulation. In the meanwhile however, if only one level can be analyzed with available time and manpower, the

streamlines at 500 mb. seem to provide a most useful analysis to represent the embedded flow in depth, and to locate the hyperbolic axis. In this study, the same general patterns were noted at 700 mb. as at 500 mb., but the features at 700 mb. were less distinct and not as pronounced.

7. SUMMARY

The case of Cleo has been presented to illustrate the proposition that the hyperbolic axis, as determined by streamline analysis at 500 mb., can serve as a kinematic feature to characterize the steering circulation, in depth, acting on a tropical storm. An awareness of changes in orientation of the axis appears useful for forecasting storm movement. Sherman and Carino [6] speculated that the shifting position of the surface hyperbolic point might lag behind changes in the upper air, influencing curvature of the storm path. If further studies can

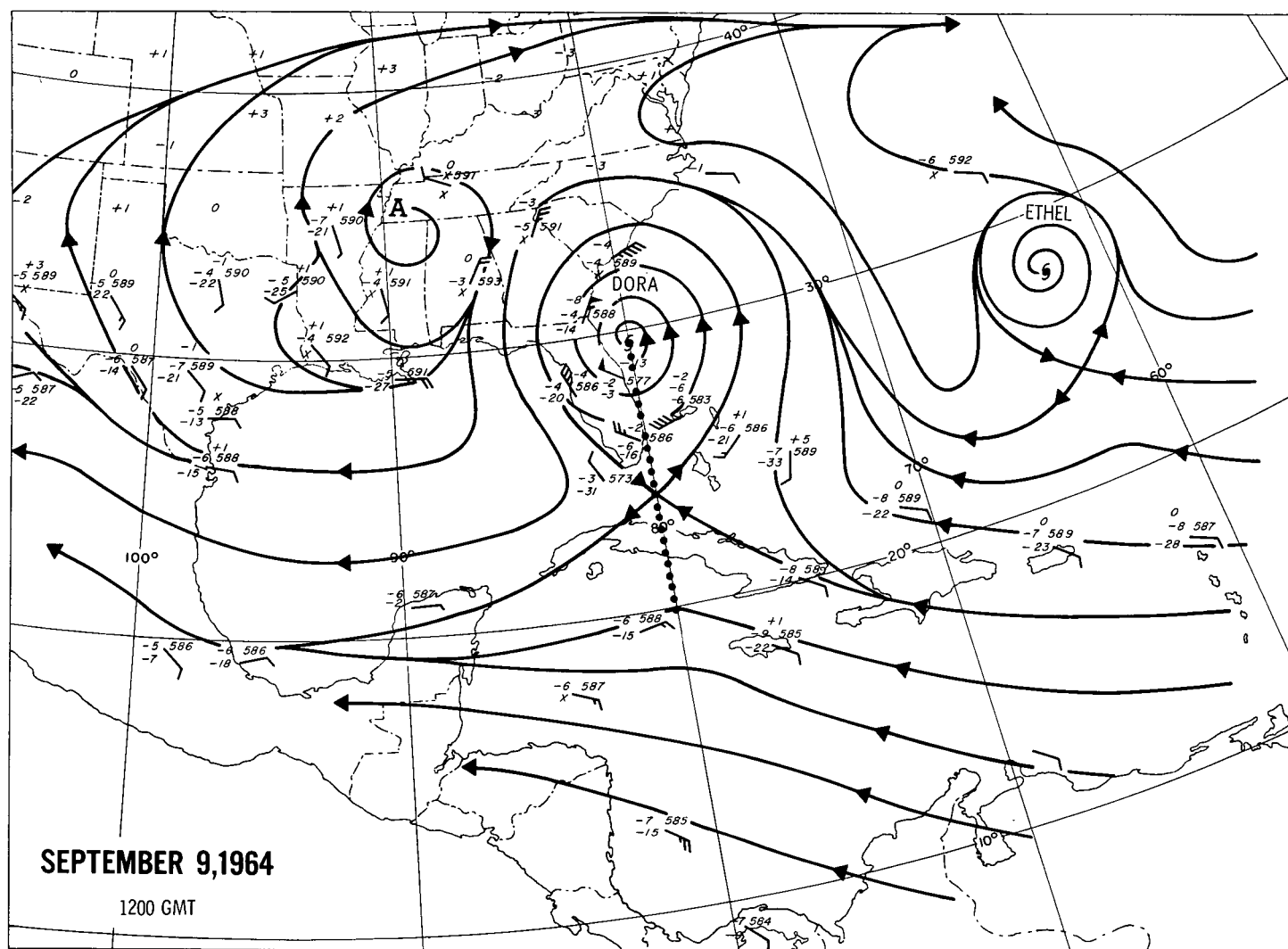


FIGURE 7.—Streamlines, hurricane Dora, 1200 GMT September 9, 1964.

demonstrate that changes in the tropical storm path lag behind reorientation of the hyperbolic axis at 500 mb., such analysis would have definitive forecasting value.

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